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GAS INTERCONNECTOR GREECE-BULGARIA

HYDRAULIC STUDY REPORT
IGB PROJECT

Signature: **IGB-04-FEED-HSR**

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Executive Director: **Valentin Stanchev**

/……/

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1. EXECUTIVE SUMMARY

The present hydraulic study presents the main results for the hydraulic modeling of entire pipeline of the Interconnector Greece Bulgaria.

Initially the hydraulic study calculations have been performed by PENSPEN – C&M Engineering Consortium. That report was based on preliminary data for IGB project (document reference: 10760-RPT-PR-00-001 rev.1).

The purpose of the hydraulic study is the achievement of a more detailed study of the entire pipeline. Current estimates include the main scenarios and added new variations of hydraulic calculations based on IGB Project – Hydraulic study update requirements.

The underground pipeline IGB will transport natural gas across the border between Greece and Bulgaria, connecting at Komotini with DESFA system and TAP pipeline(as an option) with an existing gas pipeline near the Bulgarian city of Stara Zagora. The proposed pipeline will be with a total length of 182.54 km (31.6 km in Greece and 150.94 km in Bulgaria).

The purpose of this document is to present and analyse the results of hydraulic assessment of the IGB pipeline system.

The hydraulic study main objectives are as follows:

- Assessing the capacity of the IGB gas pipeline system (BNCMY, in both directions) in free flow conditions (without compressor on the IGB routing) considering the conditions detailed below;
- Assessing the compression duty required to flow a 5 BNCMY in the future through the IGB pipeline from Greece to Bulgaria considering the conditions detailed below;

As a consequence of these high level objectives, the following secondary objectives are targeted:

- Defining the temperature profiles along the pipe and check that the minimum temperature of 6°C specified in the GMS and AGRS heaters datasheets is met and that hydrate formation is not a risk anywhere along the pipe
- Evaluating the velocity as well as the ρv^2 criteria along the pipe to check that erosion is not a risk anywhere along the pipe
- Editing some material balances corresponding to the design case of each piece of equipment of above ground installatoions for which a datasheet has been created to make sure the update of the hydraulic study does not challenge the datasheets created within the Technical design;
- Assessing of heating requirement during first filling of the pipeline

2. BASE OF HYDRAULIC SIMULATION

Below are set out the basic parameters and assumptions used in the simulation performance of this hydraulic calculation of IGB.

Hydraulic calculations of transmission pipeline Greece-Bulgaria have used basic data output contained in memorandum of the technical project.

- Tie-in with DESFA system at Komotini (National Gas Transmission System), Greece
- Direction of gas flow to Bulgaria at Kardjali Off-take (Citygas AD), Bulgaria
- Tie-in to downstream transmission system at Dimitrovgrad Off-take (Bulgartransgaz), Bulgaria
- Tie-in to downstream transmission system at Stara Zagora (Bulgartransgaz), Bulgaria

All gas flows in this document are referred to the following Gas Normal Conditions:

Normal pressure	1.01325 bara
Normal temperature	0°C

3. GAS BASE CONDITIONS

3.1. Design pressure and Maximum allowable operating pressure (MAOP)

Design pressure	80barg
Maximum allowable operating pressure (MAOP) -pipeline	75 barg
Maximum allowable operating pressure (MAOP) - compressor station	76.2 barg

The assumption is that the design pressure of stations along the Greek- Bulgarian Interconnector system is equivalent to the design pressure of the pipeline itself (i.e. 80 barg).

3.2. Greece to Bulgaria operation

The following supply and delivery pressures are applicable to the Greece to Bulgaria operation only:

Greece to Bulgaria operation		
Free Flow Condition	Supply pressure from Komotini	45 barg
	Delivery pressure to Stara Zagora	42 barg
Free Flow Condition	Supply pressure from Komotini	57 barg

	Delivery pressure to Stara Zagora	42 barg
With compression on IGB pipeline - The position of the compressor station is selected on the previous stage of the project see Point 3.10	Supply pressure from Komotini	57 barg
	Delivery pressure to Stara Zagora	52 barg

3.3. Bulgaria to Greece operation – (reverse flow case)

The following supply and delivery pressures are applicable for the Bulgaria to Greece operation only:

Bulgaria to Greece operation		
Free Flow Condition	Supply pressure from Stara Zagora	40.4 barg
	Delivery pressure to Komotini	36.23 barg

3.4. System benchmark gas temperatures

Design Temperature	60°C
Maximum gas operating temperature in the system	50°C
After-cooler exit gas temperature (Summer conditions)	50°C

3.5. Gas flow distribution from the supply facilities –Greece to Bulgaria operation:

Reference conditions (0°C,0°C);

System gas capacity	Gas Capacity (bNcmy)
Initial	3,0
Future	5,0

A load factor of 0.9 has been assumed and applied to the annual flowrates to take into account possible maintenance / delays in the operation of the pipeline system. Hence, applying this load factor, the gas flowrates are:

Reference conditions (0°C,0°C);

System gas capacity	Gas Capacity (bNcmy)	
	Initial	Future
Kardjali	**0,08**	0,08
Dimitrovgrad	**0,66**	1,09
Stara Zagora	**2,34**	3,83

All	**3**	5

Daily gas flowrates are:

Reference conditions (0°C,0°C);

System gas capacity	**Gas Capacity (mNcmd)**	
	Initial	Future
Kardjali	0,24	0,24
Dimitrovgrad	2,01	3,32
Stara Zagora	7,12	11,66
All	9,13	15,22

Note: The gas distribution with offtakes is in accordance with contracting authority Terms of reference

3.6. Gas composition

IGB should be able to handle and effectively transfer the gas which composition is within the Greek legislation (Greek Code Gas with a concentration of methane of 78.50% and typical Greek Gas with methane concentration of 94.08%). The composition of the gas and the water content, which is used in the technical project (TP) of IGB, which is confirmed in the response of the technical inquiry under No-10760 PM-TQ-002, are set out in the table below:

Table 1

Reference conditions (0°C,0°C);

	Concentration		**(mol%)**
Component	**Greek Gas**	**Standard Greek gas**	**Bulgarian Gas**
Methane (CH4)	94,08	78,50	97,8396
Ethane (C2H6)	2,80	7,57	0,8537
Propane (C3H8)	0,70	2,52	0,2792
i- Butane (iC4H10)			0,0459
n-Butane (n C4H10)	0,28 Note 1	1,58 Note 1	0,0461
i-Pentane (iC5H12)			0,0090
n-Pentane (n C5H12)	0,09 Note 2	0,63 Note 2	0,0065
Hexane (C6H14)			0,0059
Nitrogen (N2)	1,81	6,0	0,6198
Carbon Dioxide (C02)	0,22	3,0	0,2943
Oxygen (02)	0,02	0,2	0,00
ALL	100,0	100,0	100,0
The hydrocarbon dew point	-56,7°C at 55 barg	-3,9°C at 55 barg	-76,8°C at 55 barg
Lower calorific value	36,7 MJ/Nm3	38,2 MJ/Nm^3	36,1 MJ/Nm3
Upper calorific value	40,7 MJ/Nm3	42,2 MJ/Nm^3	40,1 MJ/Nm3

Notes: 1. The split of butane between n-Butane and i-Butane is not known. The C4 content is assumed to be n-Butane (Greek gas).

2. For simulation purposes, the C5H12+ component (Greek gas) will be simulated as n-Pentane.

Minimum requirements for the composition of the natural gas under the Bulgarian Regulator
Quality indicators

Designation	Description	Units	Not less than	Not more than	Notes
GCV	Higher heating value	kWh/m^3	10	12,7	Under reference conditions (25°C,20°C)
WI	Wobbe index	MJ/m^3	45	55	Under reference conditions (25°C,20°C)
D_r	Relative density	-	0,5	0,72	
SH_4	Methane	% mole	70		
CO_2	Carbon dioxide	% mole		5	
N_2	Nitrogen	% mole		10	
O_2	Oxygen	% mole		0,2	
H_2S	Hydrogen sulphide	mg/m^3		6,5	
$S+X_nS_m$	Sulfur total	mg/m^3		30	In exceptional cases, up to 100 mg/m3, for a period not exceeding 48 hours
H_2O DP	Water dewpoint	°C		-8	At pressure of 39,2 barg
C_nH_m DP	Hydrocarbons dewpoint	°C		0	At pressure of 54 barg

Notes:
1. The conditions for measuring the quantities of natural gas are pressure 1.01325 bara and temperature of 20 °C
2. The conditions for determining the higher heating value and Wobbe index are 25 °C and the conditions under 1.
3. Under the arrangements referred to in paragraph 3.2 and 3.3 of this report, there no conditions for the formation of a liquid phase

3.7. Elevation profile

Elevation profile included in the hydraulic calculation of the IGB is according Appendix 1 - the input data are the real upper elevations of gas pipe (The buried depth of pipeline).

3.8. Pipeline parameters

Outside diameter, mm	Classification EN ISO 3183	Wall thickness of pipeline, mm	Design factor
813(32”)	L450ME (X65ME)	11	0.72
		14.2	0.6
		16	0.5
		20	0.4

The pipes must be supplied with factory applied anticorrosion polyethylene coating – 3LPE and internal epoxy coating, intended for operation up to 60° C.

The hydraulic study report set out any changes to the thickness of the pipe along the length of the route – Appendix 2.

3.9. Thermal and physical properties – Pipe and Coating materials

Material	Parameter/Property	Value
Steel pipe	Thermal conductivity	50 W/(m·K)
	Thickness	As per pipe diameter
	Specific heat	500 J/(kg·K)
	Density	7900 kg/m³
Material	Parameter/Property	Value
3LPE	Thermal conductivity	0.5 W/(m·K)
	Thickness	3.5 mm
	Specific heat	1850 J/(kg·K)
	Density	949 kg/m³
Internal two-pack epoxy resin	Roughness (Rz), μm	152
	Thickness	Standart coating thickness 60-75μ

3.10. Location of facilities along the route of the pipeline

km	Facilities
0	Start point (Komotini/Greece)
0,75	GMS-1
27,79	BV-1
56,84	BV-2
81,64	AGRS Kardjali+BV-3
110,84	BV-3A
123,00	Compressor station
123,46	
128,44	BV-4
142,94	BV-4A
148,84	AGRS Dimitrovgrad(BV-5)
161,16	BV-6
182,14	GMS-2
182,54	BV-7
	(Stara Zagora/Bulgaria)

NOTE: The position of the compressor station is selected in the previous stage of the project.

3.11. Facility pressure drop

Have been devepoled two types of hydraulic calculations:
TYPE A: Hydraulic simulation with and without offtakes

Facility pressure drop

Gas metering station (GMS)	0.0 bar
Automated gas regulation station (AGRS)	0.0 bar
Block valve(BV)	0.0 bar

Note: Facility pressure drop is 0 bar due to the close values of the starting and ending pressure in hydraulic simulation. Since at low speeds the pressure drop in the AGI tends to zero is passed a value of zero. In addition, in order to be able to explore all modes in the drop in pressure in the facilities should be taken zero.

TYPE B: Hydraulic simulation without offtakes

Facility pressure drop	
Gas metering station (GMS)	0.5 bar

3.12. Modeling parameters

Modeling parameters	
Equation of state	SynerGEE provides various flow equations (equations of state) and allows for each flow equation to be assigned as a session default or on a pipe-by-pipe basis
Friction factor equation	Colebrook-White
Hydraulic Roughness	0.0152 mm

The hydraulic assessment of the IGB pipeline system has been performed using SynerGEE Gas- licensed software. A brief description of the software shown in the Appendix 3.

SynerGEE Gas pipeline modelling software identifies, predicts and helps to asset's operational challenges, enabling efficiency of gas transmission networks. SynerGEE Gas gives the results to make crucial design, planning and operating decisions.

The formula used in the program:

$$P_2 = \sqrt{P_1^2 - \frac{41{,}95.10^{-6}.G.(h_2 - h_1).P_a^2}{z.T_a} - 12{,}07.10^6 \frac{Q^2.P_b^2.G.T_{a.}.L.z.f}{(n+1)^2.e^2.D^5.T_b^2}}$$, where

- P_1 Inlet pressure, MPa
- P_2 Outlet pressure, MPa
- G Specific gravity, [-]
- f Friction factor, [-]
- T_a Average design gas-flowing temperature K
- T_b Standard temperature, K
- P_a Average operating pressure, MPa

- P_b Standard pressure, MPa
- L Length of the pipeline, m
- D Internal pipe diameter, m
- z Compressibility factor, [-]
- e Efficiency of pipeline, [-]
- h_1 Elevation of the start point, m
- h_2 Elevation of the end point, m
- n Length of the pipeline, m
- Q Gas flow, m^3/h

Notes:

- Efficiency of pipeline has been assumed – 100% (i.e. e=1)
- Compressibility factor is calculated in each segment of the model; With compression (CS) on IGB pipeline - amended scope – 0,87-0,91;

Maximum flow velocity

Good operating practices recommend a maximum flow velocity of 15 m/s regarding maintanace of allowable pressure decrease, levels of erosion and noise levels.

3.13. Environmental parameters

Pipe modelling conditions		
Environmental Scenario	Air temperatures (°C)	Ground temperature (°C)
Summer	40	22
Winter	0	6

Soil thermal conductivity	
Soil material	Thermal conductivity (W/m.K)
Dry clay	0.48

Note:The selected value for thermal conductivity is for dry clay, as the backfilling of pipeline is with soft soil.

4. METHODOLOGY AND RESULTS

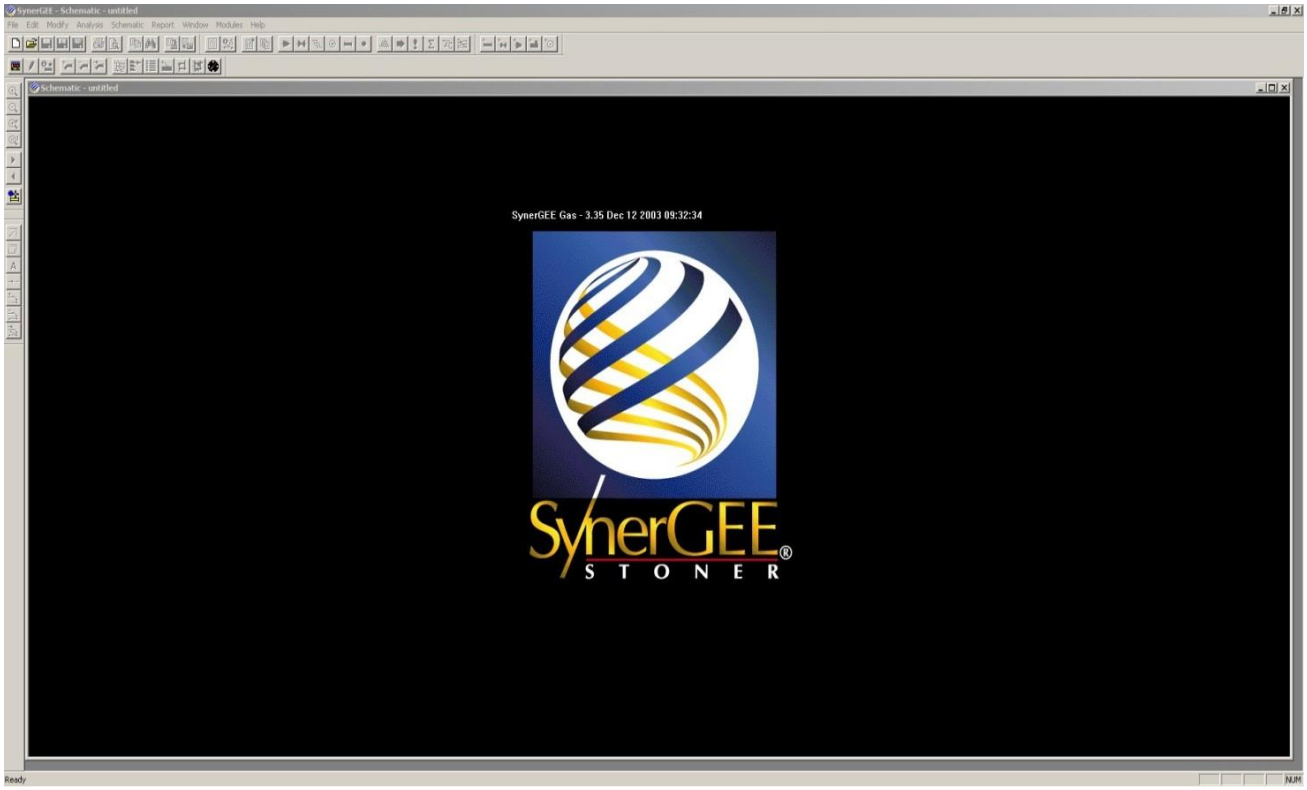
The system has been modelled, under steady state flow conditions, from tie-in with DESFA system at Komotini to tie-in at Stara Zagora and backwards.

The hydraulic study report set out any changes to the thickness of the pipe along the length of the route.

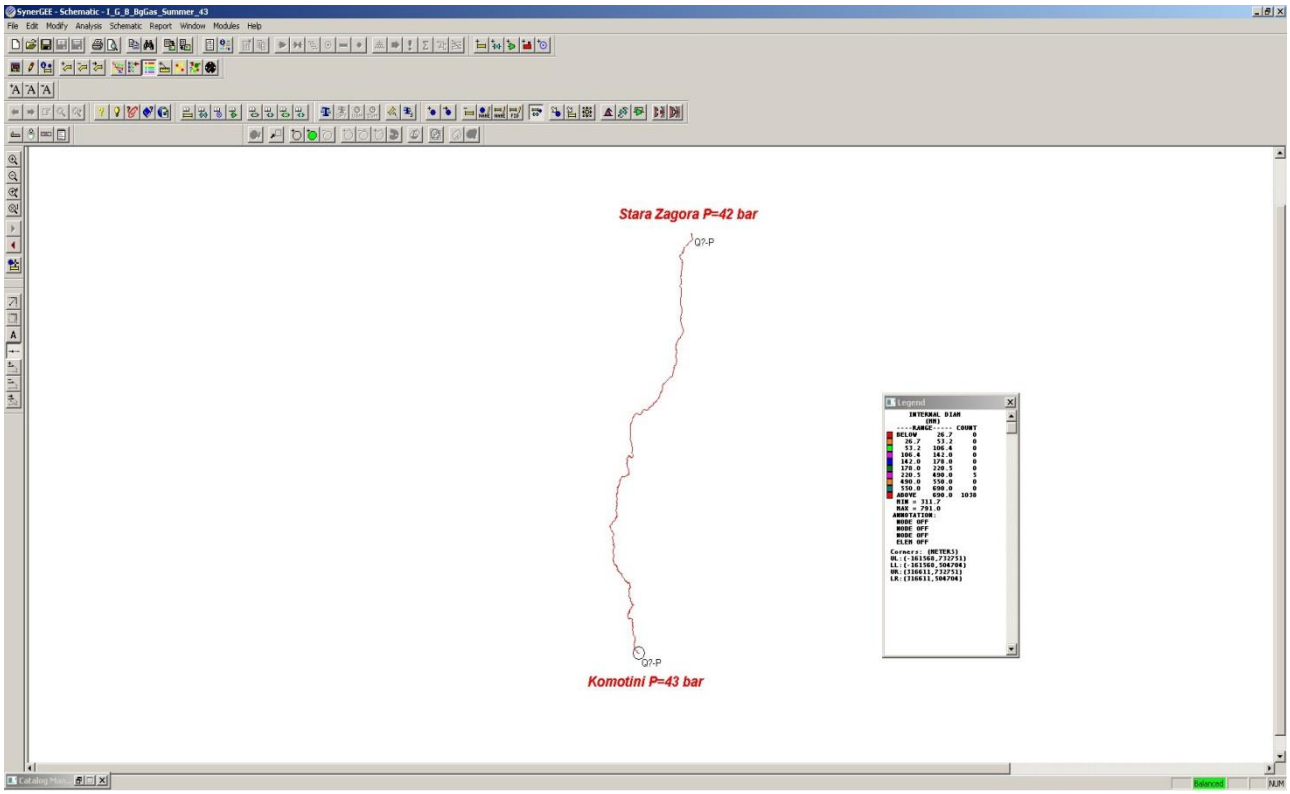
Reviewed options for hydraulic simulations are with and without offtakes at AGRS Kardjali and AGRS Dimitrovgrad.

Simulation of variants with and without compressor station are made for both direction: Greece-Bulgaria and Bulgaria-Greece.

Syner Gee Software preview



Initial page of Synergee gas



Functional screen - Grafical interface Synergee gas

TYPE A : Facility pressure drop 0.0 bar for AGI

5. HYDRAULIC SIMULATION WITH OFFTAKES – facility pressure drop 0.0 bar for AGI

Hydraulic simulation I: ***Greece to Bulgaria operation***

- Hydraulic simulation I.A. Greek Gas – winter conditions
- Hydraulic simulation I.B. Greek Gas – summer conditions
- Hydraulic simulation I.C. Bulgarian Gas – winter conditions
- Hydraulic simulation I.D. Bulgarian Gas – summer conditions

Hydraulic simulation II: ***Bulgaria to Greece operation***

- Hydraulic simulation II.A. Greek Gas – winter conditions
- Hydraulic simulation II.B. Greek Gas – summer conditions
- Hydraulic simulation II.C. Bulgarian Gas – winter conditions
- Hydraulic simulation II.D. Bulgarian Gas – summer conditions

Hydraulic simulation III: ***Greece to Bulgaria operation – Supply Pressure from Komotini with Capacity of 1.4 bcmy***

- Hydraulic simulation III.A. Greek Gas – winter conditions
- Hydraulic simulation III.B. Greek Gas – summer conditions
- Hydraulic simulation III.C. Bulgarian Gas – winter conditions
- Hydraulic simulation III.D. Bulgarian Gas – summer conditions

Hydraulic simulation IV: ***Greece to Bulgaria operation – Supply Pressure from Komotini with Capacity of 3.08 bcmy***

- Hydraulic simulation IV.A. Greek Gas – winter conditions
- Hydraulic simulation IV.B. Greek Gas – summer conditions
- Hydraulic simulation IV.C. Bulgarian Gas – winter conditions
- Hydraulic simulation IV.D. Bulgarian Gas – summer conditions

Hydraulic simulation V: ***Greece to Bulgaria operation – with Compressor Station and Capacity of 5 bcmy***

- Hydraulic simulation V.A. Greek Gas – winter conditions
- Hydraulic simulation V.B. Greek Gas – summer conditions
- Hydraulic simulation V.C. Bulgarian Gas – winter conditions
- Hydraulic simulation V.D. Bulgarian Gas – summer conditions

Hydraulic simulation VI: ***Bulgaria to Greece operation – max flow with Compressor Station***

- Hydraulic simulation VI.A. Greek Gas – winter conditions
- Hydraulic simulation VI.B. Greek Gas – summer conditions
- Hydraulic simulation VI.C. Bulgarian Gas – winter conditions
- Hydraulic simulation VI.D. Bulgarian Gas – summer conditions

All above mentioned hydraulic simulation from I to IV are free flow conditions. Simulation V and VI are with compressor station on IGB pipeline which position is selected on the previous stage of the project.
The results are shown in tables below:

I. Capacity of the IGB in free flow conditions – ***Greece to Bulgaria operation***

I.A. Greek Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	43	42	41.92	42.06	39.8	6	0	6.830	1.742	6.585	0.122	33.13	10 147	83 714	10 011	240 264	0.079
2	44	42	42.39	42.14	40.54	6	0	6.659	1.364	6.568	0.789	32.96	10 147	83 714	79 080	1 897 920	0.623
3	45	42	42.90	42.25	41.29	6	0	6.363	1.173	6.539	0.777	32.67	10 147	83 714	127 449	3 058 776	1.005
4	46	42	43.41	42.39	41.95	6	0	6.046	1.028	6.506	0.766	32.34	10 147	83 714	167 579	4 021 896	1.321
5	47	42	43.94	42.53	42	6	0	5.988	0.904	6.471	0.755	31.99	10 147	83 714	202 978	4 871 472	1.600
6	48	42	44.48	42.69	42	6	0	5.988	0.790	6.434	0.744	31.63	10 147	83 714	235 237	5 645 688	1.855
7	49	42	45.03	42.85	42	6	0	5.987	0.678	6.397	0.733	31.26	10 147	83 714	265 235	6 365 640	2.091
8	50	42	45.58	43.02	42	6	0	5.987	0.573	6.359	0.723	30.89	10 147	83 714	293 515	7 044 360	2.314
9	51	42	46.14	43.20	42	6	0	5.986	0.473	6.320	0.712	30.52	10 147	83 714	320 445	7 690 680	2.526
10	52	42	46.70	43.38	42	6	0	5.986	0.376	6.280	0.702	30.13	10 147	83 714	346 281	8 310 744	2.730
11	53	42	47.27	43.56	42	6	0	5.986	0.282	6.240	0.692	29.75	10 147	83 714	371 215	8 909 160	2.927
12	54	42	47.84	43.75	42	6	0	5.985	0.192	6.221	0.682	29.57	10 147	83 714	395 391	9 489 384	3.118
13	55	42	48.42	43.95	42	6	0	5.985	0.104	6.578	0.672	33.06	10 147	83 714	418 923	10 054 152	3.303
14	56	42	49.01	44.14	42	6	0	5.985	0.017	6.925	0.662	36.64	10 147	83 714	441 901	10 605 624	3.484
15	57	42	49.60	44.35	42	6	0	5.985	-0.067	7.262	0.653	40.29	10 147	83 714	464 397	11 145 528	3.661

Analysis:

The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad.

From the hydraulic calculations and graphical results can be seen that form 43bar to 46bar – Pmin is it at border point due to elevation.

Gas flow can be seen from graphic results and varies from 0,82 bcmy to 4,4 bcmy.

The minimum temperature varies from 1,742°C (43bar) to -0.067°C (57bar).

$\rho_{gr\ gas}$=0,764 kg/m³ ; γ (sp.gravity) $_{gr\ gas}$=0.592

Compressibility factor is calculated in each segment of the model;

Conclusions:

In the above case pressure in the area of negative temperatures is about 50.56 bar – this means that the water dew point will be around: -5 °C which is too far from the minimum temperatures in pipe.

There is no risk of hydrate formation along the pipeline.

As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

I.B. Greek Gas – summer conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	43	42	41.96	42.04	40.03	22	40	22.787	17.963	7.108	0.126	38.60	10 147	83 714	9 617	230 808	0.076
2	44	42	42.43	42.11	40.77	22	40	22.645	17.620	7.091	0.851	38.42	10 147	83 714	74 935	1 798 440	0.591
3	45	42	42.93	42.23	41.52	22	40	22.388	17.446	7.063	0.839	38.11	10 147	83 714	121 122	2 906 928	0.955
4	46	42	43.45	42.36	42	22	40	22.110	17.315	7.031	0.827	37.77	10 147	83 714	159 526	3 828 624	1.258
5	47	42	43.98	42.51	42	22	40	21.998	17.203	6.996	0.816	37.39	10 147	83 714	193 426	4 642 224	1.525
6	48	42	44.52	42.66	42	22	40	21.988	17.103	6.960	0.805	37.01	10 147	83 714	224 322	5 383 728	1.769
7	49	42	45.06	42.82	42	22	40	21.988	17.005	6.923	0.793	36.62	10 147	83 714	253 047	6 073 128	1.995
8	50	42	45.61	42.99	42	22	40	21.988	16.911	6.885	0.782	36.22	10 147	83 714	280 120	6 722 880	2.208
9	51	42	46.17	43.16	42	22	40	21.987	16.822	6.847	0.771	35.82	10 147	83 714	305 889	7 341 336	2.412
10	52	42	46.74	43.34	42	22	40	21.987	16.737	6.807	0.761	35.40	10 147	83 714	330 599	7 934 376	2.606
11	53	42	47.31	43.52	42	22	40	21.987	16.654	6.767	0.750	34.99	10 147	83 714	354 433	8 506 392	2.794
12	54	42	47.88	43.71	42	22	40	21.986	16.574	6.727	0.740	34.57	10 147	83 714	377 531	9 060 744	2.976
13	55	42	48.46	43.91	42	22	40	21.986	16.497	6.808	0.730	35.41	10 147	83 714	399 998	9 599 952	3.154
14	56	42	49.05	44.10	42	22	40	21.986	16.421	7.169	0.720	39.27	10 147	83 714	421 923	10 126 152	3.326
15	57	42	49.64	44.30	42	22	40	21.986	16.346	7.522	0.710	43.23	10 147	83 714	443 376	10 641 024	3.496

Analysis:

The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad.

From the hydraulic calculations and graphical results can be seen that form 43bar to 46bar – Pmin is it at border point due to elevation.

Gas flow can be seen from graphic results and varies from 0,82 bcmy to 4,24 bcmy.

The minimum temperature varies from 16,35°C (57bar) to 18,06°C (43bar).

ρ *gr gas*=0,764 kg/m^3; γ (sp.gravity) *gr gas*=0.592

Compressibility factor is calculated in each segment of the model;

Conclusions:

There is no risk of hydrate formation along the pipeline.

As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

I.C. Bulgarian Gas – winter conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	43	42	41.95	42.06	39.94	6	0	6.805	1.866	6.643	0.166	32.48	10 147	83 714	13 509	324 216	0.107
2	44	42	42.42	42.14	40.68	6	0	6.640	1.509	6.625	0.795	32.30	10 147	83 714	82 613	1 982 712	0.651
3	45	42	42.93	42.26	41.44	6	0	6.358	1.326	6.596	0.784	32.02	10 147	83 714	131 404	3 153 696	1.036
4	46	42	43.44	42.39	42	6	0	6.055	1.187	6.564	0.773	31.71	10 147	83 714	171 965	4 127 160	1.356
5	47	42	43.97	42.54	42	6	0	5.988	1.069	6.529	0.762	31.37	10 147	83 714	207 775	4 986 600	1.638
6	48	42	44.51	42.69	42	6	0	5.988	0.961	6.493	0.751	31.03	10 147	83 714	240 420	5 770 080	1.895
7	49	42	45.06	42.86	42	6	0	5.988	0.855	6.456	0.740	30.68	10 147	83 714	270 782	6 498 768	2.135
8	50	42	45.61	43.03	42	6	0	5.987	0.754	6.419	0.729	30.33	10 147	83 714	299 407	7 185 768	2.361
9	51	42	46.17	43.20	42	6	0	5.987	0.659	6.380	0.719	29.96	10 147	83 714	326 664	7 839 936	2.575
10	52	42	46.74	43.38	42	6	0	5.987	0.567	6.341	0.709	29.59	10 147	83 714	352 813	8 467 512	2.782
11	53	42	47.31	43.57	42	6	0	5.986	0.478	6.301	0.699	29.22	10 147	83 714	378 045	9 073 080	2.981
12	54	42	47.88	43.76	42	6	0	5.986	0.392	6.396	0.689	30.11	10 147	83 714	402 056	9 649 344	3.170
13	55	42	48.46	43.95	42	6	0	5.986	0.308	6.761	0.679	33.64	10 147	83 714	426 312	10 231 488	3.361
14	56	42	49.05	44.15	42	6	0	5.985	0.226	7.116	0.669	37.27	10 147	83 714	449 551	10 789 224	3.544
15	57	42	49.64	44.36	42	6	0	5.985	0.146	7.462	0.660	40.98	10 147	83 714	472 301	11 335 224	3.724

Analysis:

The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad.

From the hydraulic calculations and graphical results can be seen that form 43bar to 46bar – Pmin is it at border point due to elevation.

Gas flow can be seen from graphic results and varies from 0,85 bcmy to 4,46 bcmy.

The minimum temperature varies from 1,866°C (43bar) to 0.146°C (57bar).

ρ *bg gas*=0,736 kg/m^3; γ (sp.gravity) *bg gas*=0.57

Compressibility factor is calculated in each segment of the model;

Conclusions:

There is no risk of hydrate formation along the pipeline.

As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

I.D. Bulgarian Gas – summer conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	43	42	41.98	42.04	40.15	22	40	22.766	18.073	7.158	0.17	37.71	10 147	83 714	12 814	307 536	0.101
2	44	42	42.46	42.11	40.89	22	40	22.630	17.746	7.141	0.856	37.53	10 147	83 714	78 342	1 880 208	0.618
3	45	42	42.96	42.23	41.65	22	40	22.385	17.579	7.113	0.845	37.24	10 147	83 714	125 002	3 000 048	0.986
4	46	42	43.48	42.37	42	22	40	22.119	17.453	7.081	0.833	36.90	10 147	83 714	163 868	3 932 832	1.292
5	47	42	44.01	42.51	42	22	40	22.001	17.346	7.047	0.822	36.55	10 147	83 714	198 204	4 756 896	1.563
6	48	42	44.55	42.67	42	22	40	21.989	17.250	7.011	0.810	36.18	10 147	83 714	229 509	5 508 216	1.809
7	49	42	45.09	42.83	42	22	40	21.988	17.157	6.974	0.799	35.80	10 147	83 714	258 620	6 206 880	2.039
8	50	42	45.65	43.00	42	22	40	21.988	17.068	6.937	0.788	35.42	10 147	83 714	286 059	6 865 416	2.255
9	51	42	46.21	43.17	42	22	40	21.988	16.983	6.898	0.777	35.02	10 147	83 714	312 176	7 492 224	2.461
10	52	42	46.77	43.35	42	22	40	21.987	16.902	6.859	0.767	34.63	10 147	83 714	337 219	8 093 256	2.659
11	53	42	47.34	43.53	42	22	40	21.987	16.823	5.836	0.696	25.07	10 147	83 714	361 373	8 672 952	2.849
12	54	42	47.92	43.72	42	22	40	21.987	16.747	6.780	0.746	33.83	10 147	83 714	384 778	9 234 672	3.034
13	55	42	48.50	43.92	42	22	40	21.987	16.673	6.991	0.736	35.97	10 147	83 714	407 543	9 781 032	3.213
14	56	42	49.08	44.11	42	22	40	21.986	16.600	7.361	0.726	39.88	10 147	83 714	429 755	10 314 120	3.388
15	57	42	49.67	44.32	42	22	40	21.986	16.530	7.722	0.716	43.89	10 147	83 714	451 485	10 835 640	3.560

Analysis:
The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad.
From the hydraulic calculations and graphical results can be seen that form 43bar to 46bar – Pmin is it at border point due to elevation.
Gas flow can be seen from graphic results and varies from 0,84 bcmy to 4,3 bcmy.
The minimum temperature varies from 18,073°C (43bar) to 16,53°C (57bar).

ρ *bg gas*=0,736 kg/m^3 ; γ (sp.gravity) *bg gas*=0.57

Compressibility factor is calculated in each segment of the model;

Conclusions:
There is no risk of hydrate formation along the pipeline.
As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

II. Capacity of the IGB in free flow conditions – *Bulgaria to Greece operation*

II.A. Greek Gas – winter conditions

Nº	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P Dimitr., bar	P Kardzhali, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Dimitr., m^3/h	Flow Kardzhali, m^3/h	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	39.16	37.37	34.31	6	0	6.924	1.708	7.084	0.901	38.34	83 714	10 147	233 272	5 598 528	1.839

II.B. Greek Gas – summer conditions

Nº	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P Dimitr., bar	P Kardzhali, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Dimitr., m^3/h	Flow Kardzhali, m^3/h	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	39.12	37.39	34.49	22	40	22.995	18.019	7.644	0.970	44.64	83 714	10 147	222 965	5 351 160	1.758

II.C. Bulgarian Gas – winter conditions

Nº	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P Dimitr., bar	P Kardzhali, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Dimitr., m^3/h	Flow Kardzhali, m^3/h	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	39.17	37.40	34.43	6	0	6.924	1.853	7.141	0.907	37.53	83 714	10 147	236 637	5 679 288	1.866

II.D. Bulgarian Gas – summer conditions

Nº	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P Dimitr., bar	P Kardzhali, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Dimitr., m^3/h	Flow Kardzhali, m^3/h	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	39.13	37.42	34.59	22	40	22.993	18.144	7.693	0.976	43.56	83 714	10 147	226 418	5 434 032	1.785

Analysis:	Conclusions:
The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from Bulgaria to Greece. Flow rates at Komotini varies depending on the type of gas and the conditions(winter,summer) for specified initial and final pressure. From the hydraulic calculations and graphical results can be seen that Pmin is it at border point due to elevation. The minimum temperatures are 1,708°C for Greek gas –winter conditions and 1,853°C for Bulgarian gas winter conditions. ρ *gr gas*=0,764 kg/m^3 ; γ (sp.gravity) *gr gas*=0,592 ρ *bg gas*=0,736 kg/m^3 ; γ (sp.gravity) *bg gas*=0,57 Compressibility factor is calculated in each segment of the model;	There is no risk of hydrate formation along the pipeline. As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

III. Capacity of the IGB – *Greece to Bulgaria operation – Supply Pressure from Komotini with Capacity of 1.4 bcmy*

III.A. Greek Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy	ρv^2_{max} Pa
1	44.09	42	42.44	42.15	40.60	6	0	6.635	1.344	6.565	0.788	10 147	83 714	83 714	177 575	1.4	32.93

III.B. Greek Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy	ρv^2_{max} Pa
1	44.17	42	42.52	42.13	40.90	22	40	22.604	17.585	7.087	0.849	10 147	83 714	83 714	177 575	1.4	38.37

III.C. Bulgarian Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy	ρv^2_{max} Pa
1	44.02	42	42.43	42.14	40.70	6	0	6.635	1.504	6.624	0.795	10 147	83 714	83 714	177 575	1.4	32.29

III.D. Bulgarian Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy	ρv^2_{max} Pa
1	44.10	42	42.51	42.13	40.97	22	40	22.606	17.725	7.138	0.855	10 147	83 714	83 714	177 575	1.4	37.50

Analysis:	Conclusions:
The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from Greece to Bulgaria and capacity of 1,4 bcmy. From the hydraulic calculations and graphical results can be seen that Pmin is it at border point due to elevation. Temperature in AGRS Kardjali is a little less than 6°C for Greek gas –winter conditions and Bulgarian gas winter conditions , but minimum temperature is 1,344°C for Greek gas –winter conditions and 1,504°C for Bulgarian gas winter conditions along the pipeline. ρ *gr gas*=0,764 kg/m^3 γ (sp.gravity) *gr gas*=0,592 ρ *bg gas*=0,736 kg/m^3 γ (sp.gravity) *bg gas*=0,57 Compressibility factor is calculated in each segment of the model;	There is no risk of hydrate formation along the pipeline. As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

IV. Capacity of the IGB – *Greece to Bulgaria operation – Supply Pressure from Komotini with Capacity of 3.08 bcmy*

IV.A. Greek Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy	ρv^2_{max} Pa
1	50.12	42	45.64	43.04	42	6	0	5.987	0.561	6.354	0.721	10 147	83 714	296 804	390 665	3.08	30.85

IV.B. Greek Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy	ρv^2_{max} Pa
1	50.64	42	45.97	43.10	42	22	40	21.987	16.854	6.861	0.775	10 147	83 714	296 804	390 665	3.08	35.96

IV.C. Bulgarian Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{in} Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy	ρv^2_{max} Pa
1	49.91	42	45.56	43.01	42	6	0	5.987	0.764	6.422	0.730	10 147	83 714	296 804	390 665	3.08	30.35

IV.D. Bulgarian Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P Kardzhali, bar	P Dimitr., bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow Kardzhali, m^3/h	Flow Dimitr., m^3/h	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy	ρv^2_{max} Pa
1	50.41	42	45.87	43.07	42	22	40	21.988	17.033	6.921	0.784	10 147	83 714	296 804	390 665	3.08	35.25

Analysis:	**Conclusions:**
The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from	There is no risk of hydrate formation along the pipeline. As can be seen from the graph - ρv^2 criteria - erosion is not a risk

Greece to Bulgaria and capacity of 3,08 bcmy. Temperature in AGRS and GMS are approximately 2°C lower than 6°C for Greek gas –winter conditions and Bulgarian gas winter conditions , but minimum temperature is 0,561°C for Greek gas –winter conditions and 0,764°C for Bulgarian gas winter conditions along the pipeline. ρ *gr gas*=0,764 kg/m^3 γ (sp.gravity) *gr gas*=0.592 ρ *bg gas*=0,736 kg/m^3 γ (sp.gravity) *bg gas*=0.57 Compressibility factor is calculated in each segment of the model;	anywhere along the pipe.

V.A. Greek Gas – winter conditions

Before CS	P_{in} Komotini, bar	P Kardzhali, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Kardzhali, m^3/h	Flow CS, m^3/h	Flow Dimitr., m^3/h	Flow Till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	47.55	42.87	6	0	5.983	0.836	7.477	0.681	42.71	10 147	2 600	138 255	626 649	15.28	5.0205
After CS		P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	P Dimitr., bar	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy
		56.76	52	6	0	39.998	30.534	9.503	5.164	68.99	54.23	6.74	0.0624	485 794	634 196	5

V.B. Greek Gas – summer conditions

Before CS	P_{in} Komotini, bar	P Kardzhali, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Kardzhali, m^3/h	Flow CS, m^3/h	Flow Dimitr., m^3/h	Flow Till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	46.84	41.59	22	40	21.984	16.970	8.358	0.752	53.37	10 147	3 100	138 255	627 149	15.30	5.0244
After CS		P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	P Dimitr., bar	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy
		56.80	52	22	40	39.999	34.392	9.563	5.195	69.87	54.26	7.91	0.0744	485 794	634 196	5

V.C. Bulgarian Gas – winter conditions

Before CS	P_{in} Komotini, bar	P Kardzhali, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Kardzhali, m^3/h	Flow CS, m^3/h	Flow Dimitr., m^3/h	Flow Till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	47.84	43.31	6	0	5.984	1.219	7.487	0.685	41.26	10 147	2 600	138 255	626 649	15.28	5.0205
After CS		P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	P Dimitr., bar	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy
		56.64	52	6	0	39.998	30.42	9.587	5.21	67.65	54.17	6.48	0.0624	485 794	634 196	5

V.D. Bulgarian Gas – summer conditions

Before CS	P_{in} Komotini, bar	P Kardzhali, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Kardzhali, m^3/h	Flow CS, m^3/h	Flow Dimitr., m^3/h	Flow Till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	47.17	42.12	22	40	21.985	17.361	8.333	0.753	51.11	10 147	3 100	138 255	627 149	15.30	5.0244
After CS		P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	P Dimitr., bar	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow Bulgaria, m^3/h	Flow Bulgaria, bcmy
		56.67	52	22	40	39.999	34.375	9.65	5.243	68.54	54.19	7.59	0.0624	485 794	634 196	5

Analysis:
The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad and compressor station at km 123,00-123,46. Greece to Bulgaria operation with capacity of 5 bcmy.
Suction pressure varies from 41,59bar to 43,31bar.
Required power for Compressor station varies from 6,48 MW for Bulgarian gas winter conditions to 7,91 MW for Greek gas summer conditions.

ρ *gr gas*=0,764 kg/m^3

γ (sp.gravity) *gr gas*=0.592

ρ *bg gas*=0,736 kg/m^3

γ (sp.gravity) *bg gas*=0.57

Compressibility factor is calculated in each segment of the model;

Conclusions:
There is no risk of hydrate formation along the pipeline.
As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

VI. Capacity of the IGB – *Bulgaria to Greece operation – max flow with Compressor Station*

VI.A. Greek Gas – winter conditions

Before CS	P_{in} St. Zagora, bar	P Dimitr., bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Dimitr., m^3/h	Flow CS, m^3/h	Flow Kardzhali, m^3/h	Flow Till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy
	40.4	32.55	28.19	6	0	5.979	0.604	14.05	9.98	150.82	138 255	7 800	10 147	641 996	18.73	6.1515
After CS		P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	P Kardzhali, bar	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Greece, m^3/h	Flow Greece, bcmy
		68.30	57	6	0	39.992	25.084	7.98	0.576	48.65	64.10	22.4	0.1872	634 196	634 196	5

VI.B. Greek Gas – summer conditions

Before CS	P_{in} St. Zagora, bar	P Dimitr., bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Dimitr., m^3/h	Flow CS, m^3/h	Flow Kardzhali, m^3/h	Flow Till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy
	40.4	31.82	27.01	22	40	21.98	16.776	15.48	10.78	183.08	138 255	8 700	10 147	642 896	18.75	6.159
After CS		P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	P Kardzhali, bar	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Greece, m^3/h	Flow Greece, bcmy
		68.50	57	22	40	39.996	31.068	8.21	0.58	51.50	64.29	25.2	0.2088	634 196	634 196	5

VI.C. Bulgarian Gas – winter conditions

Before CS	P_{in} St. Zagora, bar	P Dimitr., bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Dimitr., m^3/h	Flow CS, m^3/h	Flow Kardzhali, m^3/h	Flow Till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy
	40.4	32.8	28.61	6	0	5.98	1.003	14.05	10.04	145.29	138 255	7 800	10 147	641 996	18.73	6.1515
After CS		P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	P Kardzhali, bar	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Greece, m^3/h	Flow Greece, bcmy
		68.02	57	6	0	39.992	24.983	8.054	0.583	47.74	63.93	22	0.1872	634 196	634 196	5

VI.D. Bulgarian Gas – summer conditions

Before CS	P_{in} St. Zagora, bar	P Dimitr., bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Dimitr., m^3/h	Flow CS, m^3/h	Flow Kardzhali, m^3/h	Flow Till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy
	40.4	32.11	27.51	22	40	21.981	17.183	15.43	10.85	175.23	138 255	8 500	10 147	642 696	18.74	6.157
After CS		P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	P Kardzhali, bar	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Greece, m^3/h	Flow Greece, bcmy
		68.22	57	22	40	39.996	31.11	8.284	0.587	50.51	64.11	24.6	0.204	634 196	634 196	5

Analysis:

The above calculations applied hydraulic simulation with offtakes for AGRS Kardjali and AGRS Dimitrovgrad and compressor station at km 123,00-123,46. Bulgaria to Greece operation with maximum flow.

Suction pressure varies from 27,01bar to 28,61bar.

Required power for Compressor station varies from 22 MW for Bulgarian gas winter conditions to 25,2 MW for Greek gas summer conditions.

ρ *gr gas*=0,764 kg/m^3

γ (sp.gravity) *gr gas*=0.592

ρ *bg gas*=0,736 kg/m^3

γ (sp.gravity) *bg gas*=0.57

Compressibility factor is calculated in each segment of the model;

Conclusions:

There is no risk of hydrate formation along the pipeline.

As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

6. HYDRAULIC SIMULATION WITHOUT OFFTAKES - facility pressure drop 0.0 bar for AGI

Hydraulic simulation I: ***Greece to Bulgaria operation***

- Hydraulic simulation I.A. Greek Gas – winter conditions
- Hydraulic simulation I.B. Greek Gas – summer conditions
- Hydraulic simulation I.C. Bulgarian Gas – winter conditions
- Hydraulic simulation I.D. Bulgarian Gas – summer conditions
- Hydraulic simulation I.E. Greek Code Gas – winter conditions
- Hydraulic simulation I.F. Greek Code Gas – summer conditions

Hydraulic simulation II: ***Bulgaria to Greece operation***

- Hydraulic simulation II.A. Greek Gas – winter conditions
- Hydraulic simulation II.B. Greek Gas – summer conditions
- Hydraulic simulation II.C. Bulgarian Gas – winter conditions
- Hydraulic simulation II.D. Bulgarian Gas – summer conditions
- Hydraulic simulation II.E. Greek Code Gas – winter conditions
- Hydraulic simulation II.F. Greek Code Gas – summer conditions

Hydraulic simulation III: ***Greece to Bulgaria operation – Supply Pressure from Komotini with Capacity of 1.4 bcmy***

- Hydraulic simulation III.A. Greek Gas – winter conditions
- Hydraulic simulation III.B. Greek Gas – summer conditions
- Hydraulic simulation III.C. Bulgarian Gas – winter conditions
- Hydraulic simulation III.D. Bulgarian Gas – summer conditions
- Hydraulic simulation III.E. Greek Code Gas – winter conditions
- Hydraulic simulation III.F. Greek Code Gas – summer conditions

Hydraulic simulation IV: ***Greece to Bulgaria operation – Supply Pressure from Komotini with Capacity of 3.08 bcmy***

- Hydraulic simulation IV.A. Greek Gas – winter conditions
- Hydraulic simulation IV.B. Greek Gas – summer conditions
- Hydraulic simulation IV.C. Bulgarian Gas – winter conditions
- Hydraulic simulation IV.D. Bulgarian Gas – summer conditions
- Hydraulic simulation IV.E. Greek Code Gas – winter conditions
- Hydraulic simulation IV.F. Greek Code Gas – summer conditions

Hydraulic simulation V: ***Greece to Bulgaria operation – with Compressor Station and Capacity of 5 bcmy***

- Hydraulic simulation V.A. Greek Gas – winter conditions
- Hydraulic simulation V.B. Greek Gas – summer conditions
- Hydraulic simulation V.C. Bulgarian Gas – winter conditions
- Hydraulic simulation V.D. Bulgarian Gas – summer conditions
- Hydraulic simulation V.E. Greek Code Gas – winter conditions
- Hydraulic simulation V.F. Greek Code Gas – summer conditions

Hydraulic simulation VI: ***Bulgaria to Greece operation – max flow with Compressor Station***

- Hydraulic simulation VI.A. Greek Gas – winter conditions
- Hydraulic simulation VI.B. Greek Gas – summer conditions
- Hydraulic simulation VI.C. Bulgarian Gas – winter conditions
- Hydraulic simulation VI.D. Bulgarian Gas – summer conditions

All above mentioned hydraulic simulation from I to IV are free flow conditions. Simulation V and VI are with compressor station on IGB pipeline which position is selected on the previous stage of the project.
The results are shown in tables below:

I. Capacity of the IGB in free flow conditions – ***Greece to Bulgaria operation without offtakes***

I.A. Greek Gas – winter conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	43	42	39.83	6	0	6.835	1.859	1.431	1.064	1.56	89 436	2 146 464	0.705
2	44	42	40.59	6	0	6.719	1.436	2.490	1.805	4.74	155 658	3 735 792	1.227
3	45	42	41.36	6	0	6.455	1.235	3.246	2.299	8.05	203 168	4 876 032	1.602
4	46	42	42	6	0	6.162	1.088	3.874	2.683	11.47	242 838	5 828 112	1.915
5	47	42	42	6	0	6.018	0.963	4.427	2.999	14.97	277 939	6 670 536	2.191
6	48	42	42	6	0	5.988	0.852	4.929	3.269	18.56	309 985	7 439 640	2.444
7	49	42	42	6	0	5.987	0.745	5.394	3.503	22.23	339 818	8 155 632	2.679
8	50	42	42	6	0	5.987	0.640	5.830	3.709	25.97	367 969	8 831 256	2.901
9	51	42	42	6	0	5.987	0.541	6.243	3.893	29.78	394 791	9 474 984	3.113
10	52	42	42	6	0	5.986	0.446	6.637	4.058	33.65	420 538	10 092 912	3.316
11	53	42	42	6	0	5.986	0.354	7.016	4.207	37.61	445 394	10 689 456	3.511
12	54	42	42	6	0	5.986	0.264	7.381	4.343	41.62	469 504	11 268 096	3.702
13	55	42	42	6	0	5.985	0.177	7.734	4.467	45.70	492 976	11 831 424	3.887
14	56	42	42	6	0	5.985	0.092	8.077	4.581	49.84	515 901	12 381 624	4.067
15	57	42	42	6	0	5.985	0.008	8.411	4.686	54.05	538 351	12 920 424	4.244

Analysis:	**Conclusions:**
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad. From the hydraulic calculations and graphical results can be seen that form 43bar to 45bar – Pmin is it at border point due to elevation. Gas flow can be seen from graphic results and varies from 0,705 bcmy to 4,244 bcmy. The minimum temperature varies from 1,859°C (43bar) to -0.008°C (57bar). From 43bar to 45bar minimum temperature of 6°C specified in the GMS and AGRS heaters datasheet are insured. From 46bar to 57bar temperatures in the GMS and AGRS are lower than 6°C.	There is no risk of hydrate formation along the pipeline. As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

ρ *gr gas*=0,764 kg/m^3 γ (sp.gravity) *gr gas*=0.592 Compressibility factor is calculated in each segment of the model;	

I.B. Greek Gas – summer conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	43	42	40.06	22	40	22.792	18.075	1.538	1.144	1.81	89 075	2 137 800	0.702
2	44	42	40.83	22	40	22.699	17.690	2.617	1.900	5.23	151 606	3 638 544	1.195
3	45	42	41.60	22	40	22.472	17.506	3.396	2.410	8.81	196 923	4 726 152	1.553
4	46	42	42	22	40	22.216	17.372	4.046	2.807	12.51	234 857	5 636 568	1.852
5	47	42	42	22	40	22.032	17.259	4.619	3.136	16.30	268 451	6 442 824	2.116
6	48	42	42	22	40	21.988	17.160	5.140	3.416	20.18	299 127	7 179 048	2.358
7	49	42	42	22	40	21.988	17.067	5.623	3.660	24.16	327 684	7 864 416	2.583
8	50	42	42	22	40	21.988	16.974	6.077	3.876	28.21	354 623	8 510 952	2.796
9	51	42	42	22	40	21.988	16.887	6.507	4.068	32.35	380 281	9 126 744	2.998
10	52	42	42	22	40	21.987	16.802	6.918	4.242	36.56	404 899	9 717 576	3.192
11	53	42	42	22	40	21.987	16.720	7.313	4.399	40.86	428 654	10 287 696	3.380
12	54	42	42	22	40	21.987	16.642	7.694	4.542	45.23	451 682	10 840 368	3.561
13	55	42	42	22	40	21.986	16.565	8.063	4.673	49.67	474 089	11 378 136	3.738
14	56	42	42	22	40	21.986	16.491	8.421	4.793	54.18	495 959	11 903 016	3.910
15	57	42	42	22	40	21.986	16.417	8.770	4.904	58.76	517 363	12 416 712	4.079

Analysis:
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad.
From the hydraulic calculations and graphical results can be seen that form 43bar to 45bar – Pmin is it at border point due to elevation.
Gas flow can be seen from graphic results and varies from 0,702 bcmy to 4,079 bcmy.
The minimum temperature varies from 18,075°C (43bar) to -16,417°C (57bar).

ρ *gr gas*=0,764 kg/m^3; γ (sp.gravity) *gr gas*=0,592

Compressibility factor is calculated in each segment of the model;

Conclusions:
There is no risk of hydrate formation along the pipeline.
As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

I.C. Bulgarian Gas – winter conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	43	42	39.97	6	0	6.810	1.978	1.495	1.112	1.64	92 670	2 224 080	0.731
2	44	42	40.74	6	0	6.697	1.578	2.567	1.862	4.85	159 097	3 818 328	1.254
3	45	42	41.51	6	0	6.446	1.386	3.337	2.366	8.20	207 056	4 969 344	1.632
4	46	42	42	6	0	6.165	1.245	3.978	2.758	11.65	247 170	5 932 080	1.949
5	47	42	42	6	0	6.018	1.126	4.543	3.081	15.19	282 688	6 784 512	2.229
6	48	42	42	6	0	5.988	1.019	5.057	3.357	18.82	315 124	7 562 976	2.484
7	49	42	42	6	0	5.988	0.918	5.532	3.597	22.52	345 326	8 287 824	2.723
8	50	42	42	6	0	5.987	0.819	5.978	3.809	26.30	373 824	8 971 776	2.947
9	51	42	42	6	0	5.987	0.724	6.401	3.997	30.16	400 796	9 619 104	3.160
10	52	42	42	6	0	5.987	0.633	6.805	4.167	34.08	427 036	10 248 864	3.368
11	53	42	42	6	0	5.987	0.546	7.193	4.321	38.08	452 192	10 852 608	3.565
12	54	42	42	6	0	5.986	0.461	7.567	4.461	42.14	476 587	11 438 088	3.757
13	55	42	42	6	0	5.986	0.378	7.929	4.589	46.27	500 335	12 008 040	3.945
14	56	42	42	6	0	5.986	0.298	8.280	4.706	50.46	523 523	12 564 552	4.127
15	57	42	42	6	0	5.985	0.218	8.622	4.815	54.71	546 226	13 109 424	4.306

Analysis:
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad.
From the hydraulic calculations and graphical results can be seen that form 43bar to 45bar – Pmin is it at border point due to elevation.
Gas flow can be seen from graphic results and varies from 0,731 bcmy to 4,306 bcmy.
The minimum temperature varies from 1,978°C (43bar) to -0.218°C (57bar).
From 43bar to 45bar minimum temperature of 6°C specified in the GMS and AGRS heaters datasheet are insured.
From 46bar to 57bar temperatures in the GMS and AGRS are lower

Conclusions:
There is no risk of hydrate formation along the pipeline.
As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

than 6°C. $\rho_{bg\ gas}$=0,736 kg/m^3 γ (sp.gravity) *bg gas*=0,57 Compressibility factor is calculated in each segment of the model;	

I.D. Bulgarian Gas – summer conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	43	42	40.18	22	40	22.770	18.179	1.600	1.190	1.88	92 025	2 208 600	0.726
2	44	42	40.95	22	40	22.681	17.814	2.693	1.956	5.34	154 917	3 718 008	1.221
3	45	42	41.73	22	40	22.464	17.636	3.487	2.475	8.95	200 734	4 817 616	1.583
4	46	42	42	22	40	22.219	17.508	4.150	2.881	12.68	239 143	5 739 432	1.885
5	47	42	42	22	40	22.033	17.400	4.735	3.217	16.50	273 179	6 556 296	2.154
6	48	42	42	22	40	21.989	17.305	5.267	3.503	20.42	304 269	7 302 456	2.399
7	49	42	42	22	40	21.989	17.216	5.761	3.753	24.43	333 216	7 997 184	2.627
8	50	42	42	22	40	21.988	17.129	6.224	3.974	28.51	360 523	8 652 552	2.842
9	51	42	42	22	40	21.988	17.044	6.664	4.172	32.68	386 532	9 276 768	3.047
10	52	42	42	22	40	21.988	16.964	7.085	4.349	36.95	411 484	9 875 616	3.244
11	53	42	42	22	40	21.987	16.886	7.488	4.511	41.27	435 561	10 453 464	3.434
12	54	42	42	22	40	21.987	16.811	7.878	4.658	45.68	458 897	11 013 528	3.618
13	55	42	42	22	40	21.987	16.738	8.256	4.792	50.17	481 602	11 558 448	3.797
14	56	42	42	22	40	21.987	16.667	8.623	4.916	54.73	503 761	12 090 264	3.972
15	57	42	42	22	40	21.986	16.598	8.980	5.030	59.35	525 443	12 610 632	4.143

Analysis:
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad.
From the hydraulic calculations and graphical results can be seen that form 43bar to 45bar – Pmin is it at border point due to elevation.
Gas flow can be seen from graphic results and varies from 0,726 bcmy to 4,143 bcmy.
The minimum temperature varies from 18,179°C (43bar) to -16,598°C (57bar).

$\rho_{bg\ gas}$=0,736 kg/m^3

Conclusions:
There is no risk of hydrate formation along the pipeline.
As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

γ (sp.gravity) *bg gas*=0,57 Compressibility factor is calculated in each segment of the model;	

I.E. Greek Code Gas – winter conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	45	42	40.52	6	0	6.514	0.361	2.806	1.978	38.78	186 048	4 465 152	1.467
2	57	42	42	6	0	5.982	-1.240	7.406	4.051	50.13	507 435	12 178 440	4.001

I.F. Greek Code Gas – summer conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	45	42	40.87	22	40	22.517	16.769	2.968	2.098	8.05	180 109	4 322 616	1.420
2	57	42	42	22	40	21.983	15.377	7.787	4.297	55.42	484 174	11 620 176	3.817

Analysis: The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad. ρ *gr code gas*=0,914 kg/m^3 γ (sp.gravity) *grcode gas*=0,707 Compressibility factor is calculated in each segment of the model;	**Conclusions:** There is no risk of hydrate formation along the pipeline. As can be seen from - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

II. Capacity of the IGB in free flow conditions – *Bulgaria to Greece operation without offtakes*

II.A. Greek Gas – winter conditions

Nº	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.43	6	0	6.773	1.583	4.816	3.266	17.72	256 498	6 155 952	2.022

II.B. Greek Gas – summer conditions

Nº	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.61	22	40	22.851	17.900	4.976	3.382	18.92	246 302	5 911 248	1.942

II.C. Bulgarian Gas – winter conditions

Nº	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.55	6	0	6.780	1.734	4.915	3.336	17.78	259 847	6 236 328	2.049

II.D. Bulgarian Gas – summer conditions

Nº	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.72	22	40	22.855	18.031	5.076	3.452	18.96	249 735	5 993 640	1.969

II.E. Greek Code Gas – winter conditions

№	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	33.80	6	0	6.715	0.714	4.356	2.934	17.34	243 334	5 840 016	1.918

II.F.Greek Code Gas – summer conditions

№	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.05	22	40	22.804	17.161	4.518	3.054	18.66	232 269	5 574 456	1.831

Analysis:

The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from Bulgaria to Greece.

Flow rates at Komotini varies depending on the type of gas and the conditions(winter,summer) for specified initial and final pressure.

From the hydraulic calculations and graphical results can be seen that Pmin is it at border point due to elevation.

The minimum temperatures are 1,583°C for Greek gas –winter conditions and 1,734°C for Bulgarian gas winter conditions.

ρ *gr gas*=0,764 kg/m³; γ (sp.gravity) *gr gas*=0,592

ρ *bg gas*=0,736 kg/m³; γ (sp.gravity) *bg gas*=0,57

ρ *gr code gas*=0,914 kg/m³; γ (sp.gravity) *grcode gas*=0,707

Compressibility factor is calculated in each segment of the model;

Conclusions:

There is no risk of hydrate formation along the pipeline.

As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

Capacity of the IGB – *Greece to Bulgaria operation without offtakes – Supply Pressure from Komotini with Capacity of 1.4 bcmy*

III.A. Greek Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/h	Flow St. Zagora, bcmy
1	44.43	42	40.93	6	0	6.611	1.339	2.839	2.038	6.16	177 575	4.26	1.4

III.B. Greek Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/h	Flow St. Zagora, bcmy
1	44.55	42	41.25	22	40	22.581	17.580	3.064	2.196	7.17	177 575	4.26	1.4

III.C. Bulgarian Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/h	Flow St. Zagora, bcmy
1	44.36	42	41.01	6	0	6.613	1.500	2.864	2.061	6.04	177 575	4.26	1.4

III.D. Bulgarian Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/h	Flow St. Zagora, bcmy
1	44.47	42	41.31	22	40	22.586	17.722	3.086	2.217	7.01	177 575	4.26	1.4

III.E. Greek Code Gas – winter conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	44.80	42	40.37	6	0	6.586	0.404	2.679	1.898	6.56	177 575	4.26	1.4

III.F. Greek Code Gas – summer conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	44.94	42	40.82	22	40	22.537	16.781	2.927	2.072	7.83	177 575	4.26	1.4

Analysis:

The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from Greece to Bulgaria and capacity of 1,4 bcmy.

From the hydraulic calculations and graphical results can be seen that Pmin is it at border point due to elevation.

Temperature in AGRS Kardjali is a little less than 6°C for Greek gas –winter conditions and Bulgarian gas winter conditions , but minimum temperature is 1,339°C for Greek gas –winter conditions and 1,50°C for Bulgarian gas winter conditions along the pipeline.

ρ *gr gas*=0,764 kg/m³; γ (sp.gravity) *gr gas*=0,592

ρ *bg gas*=0,736 kg/m³; γ (sp.gravity) *bg gas*=0,57

ρ *gr code gas*=0,914 kg/m³ ; γ (sp.gravity) *grcode gas*=0,707

Compressibility factor is calculated in each segment of the model;

Conclusions:

There is no risk of hydrate formation along the pipeline.

As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

III. Capacity of the IGB – *Greece to Bulgaria operation without offtakes – Supply Pressure from Komotini with Capacity of 3.08 bcmy*

IV.A. Greek Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	50.84	42	42	6	0	5.987	0.556	6.180	3.865	29.18	390 665	9.38	3.08

IV.B. Greek Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	51.42	42	42	22	40	21.987	16.851	6.681	4.143	34.10	390 665	9.38	3.08

IV.C. Bulgarian Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	50.62	42	42	6	0	5.987	0.760	6.241	3.927	28.67	390 665	9.38	3.08

IV.D. Bulgarian Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	51.16	42	42	22	40	21.988	17.031	6.734	4.202	33.38	390 665	9.38	3.08

IV.E. Greek Code Gas – winter conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	51.86	42	42	6	0	5.984	-0.642	5.790	3.505	30.64	390 665	9.38	3.08

IV.F. Greek Code Gas – summer conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	52.59	42	42	22	40	21.985	15.815	6.345	3.810	36.80	390 665	9.38	3.08

Analysis:
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from Greece to Bulgaria and capacity of 3,08 bcmy.
Temperature in AGRS and GMS are approximately 2°C lower than 6°C for Greek gas –winter conditions and Bulgarian gas winter conditions , but minimum temperature is 0,556°C for Greek gas – winter conditions and 0,76°C for Bulgarian gas winter conditions along the pipeline.

ρ *gr gas*=0,764 kg/m³; γ (sp.gravity) *gr gas*=0,592

ρ *bg gas*=0,736 kg/m³; γ (sp.gravity) *bg gas*=0,57

ρ *gr code gas*=0,914 kg/m³ ; γ (sp.gravity) *grcode gas*=0,707

Compressibility factor is calculated in each segment of the model;

Conclusions:
In the above case pressure in the area of negative temperatures is about 45.7 bar – this means that the water dew point will be around: -7 °C which is too far from the minimum temperatures in pipe.
There is no risk of hydrate formation along the pipeline.
As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

Capacity of the IGB – *Greece to Bulgaria operation without offtakes – with Compressor Station and Capacity of 5 bcmy*

V.A. Greek Gas – winter conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy	ρv^2_{max} Pa
	57	42.69	6	0	5.983	-0.398	7.628	5.549	2 900		637 096	15.29	5.0229	44.45
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy	ρv^2_{max} Pa
	58.29	52	6	0	39.998	31.137	9.073	6.378	7.54	0.0696	634 196	15.22	5	65.89

V.B. Greek Gas – summer conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy	ρv^2_{max} Pa
	57	41.40	22	40	21.984	15.845	8.529	6.048	3 300		637 496	15.30	5.026	55.58
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy	ρv^2_{max} Pa
	58.34	52	22	40	39.999	34.459	9.208	6.372	8.81	0.0792	634 196	15.22	5	64.78

V.C. Bulgarian Gas – winter conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy	ρv^2_{max} Pa
	57	43.15	6	0	5.984	-0.129	7.635	5.618	2 800		636 996	15.29	5.022	42.90
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy	ρv^2_{max} Pa
	58.13	52	6	0	39.998	31.081	9.142	6.448	7.26	0.0672	634 196	15.22	5	61.51

V.D. Bulgarian Gas – summer conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy	ρv^2_{max} Pa
	57	41.94	22	40	21.985	16.190	8.499	6.107	3 200		637 396	15.30	5.0252	53.16
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy	ρv^2_{max} Pa
	58.17	52	22	40	39.999	34.489	9.28	6.444	8.45	0.0768	634 196	15.22	5	63.38

Analysis:

The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and compressor station at km 123,00-123,46. Greece to Bulgaria operation with capacity of 5 bcmy.

Temperature in AGRS Kardjali and GMS-1 are lower than 6°C for Greek gas –winter conditions and Bulgarian gas winter conditions , and minimum temperature is -0,398°C for Greek gas –winter conditions approximately 8km before BV-3A and -0,129°C for Bulgarian gas winter conditions at the same point.

Suction pressure varies from 41,4bar to 43,15bar.

Required power for Compressor station varies from 7,26 MW for Bulgarian gas winter conditions to 8,81 MW for Greek gas summer conditions.

ρ *gr gas*=0,764 kg/m^3

γ (sp.gravity) *gr gas*=0,592

ρ *bg gas*=0,736 kg/m^3

γ (sp.gravity) *bg gas*=0,57

Compressibility factor is calculated in each segment of the model;

Conclusions:

In the all above cases pressure in the area of negative temperatures is about 51-52 bar – this means that the water dew point will be around: -4.5 °C to - 5 °C which is too far from the minimum temperatures in pipe. There is no risk of hydrate formation along the pipeline.

As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

V.E. Greek Code Gas – winter conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	40.61	6	0	5.979	-2.551	7.448	5.095	50.70	3 300		637 496	15.30	5.026
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
	59.01	52	6	0	39.998	31.303	8.626	5.971	68.01	8.82	0.0792	634 196	15.22	5

V.F. Greek Code Gas – summer conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	38.80	22	40	21.980	13.673	8.579	5.668	67.27	3 500		637 696	15.305	5.028
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
	59.07	52	22	40	39.999	34.218	8.755	5.965	70.06	10.56	0.084	634 196	15.22	5

Analysis:

The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and compressor station at km 123,00-123,46. Greece to Bulgaria operation with capacity of 5 bcmy.

Suction pressure varies from 38,8bar to 40,61bar.

Required power for Compressor station varies from 8,82 MW for Bulgarian gas winter conditions to 10,56 MW for Greek gas summer conditions.

ρ *grcode gas*=0,914 kg/m^3; γ (sp.gravity) *grcode gas*=0,707

Compressibility factor is calculated in each segment of the model;

Conclusions:

In above case pressure in the area of negative temperatures is about 42-43 bar – this means that the water dew point will be around: -7 °C to -7.5 °C which is too far from the minimum temperatures in pipe.

There is no risk of hydrate formation along the pipeline.

As can be seen from the - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

Capacity of the IGB – *Bulgaria to Greece operation without offtakes – max flow with Compressor Station*

VI.A. Greek Gas – winter conditions

Before CS	P_{in} St. Zagora, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy	ρv^2_{max} Pa
	40.4	31.18	6	0	5.986	1.904	10.72	8.187	6 900		641 096	15.39	5.054	87.80
After CS	P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Komotini, mcmd	Flow Komotini, bcmy	ρv^2_{max} Pa
	68.18	57	6	0	39.992	23.5	7.979	5.378	19.4	0.1656	634 196	15.22	5	48.64

VI.B. Greek Gas – summer conditions

Before CS	P_{in} St. Zagora, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy	ρv^2_{max} Pa
	40.4	30.36	22	40	21.986	18.061	11.87	8.839	7 500		641 696	15.4	5.059	107.65
After CS	P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Komotini, mcmd	Flow Komotini, bcmy	ρv^2_{max} Pa
	68.38	57	22	40	39.996	28.368	8.21	5.361	21.4	0.18	634 196	15.22	5	51.50

VI.C. Bulgarian Gas – winter conditions

Before CS	P_{in} St. Zagora, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy	ρv^2_{max} Pa
	40.4	31.48	6	0	5.987	2.187	10.8	8.253	6 800		640 996	15.38	5.0536	85.85
After CS	P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Komotini, mcmd	Flow Komotini, bcmy	ρv^2_{max} Pa
	67.91	57	6	0	39.991	23.535	8.051	5.453	19.1	0.1632	634 196	15.22	5	47.71

VI.D. Bulgarian Gas – summer conditions

Before CS	P_{in} St. Zagora, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy	ρv^2_{max} Pa
	40.4	30.7	22	40	21.987	18.344	11.81	8.896	7 400		641 596	15.4	5.058	102.65
After CS	P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Komotini, mcmd	Flow Komotini, bcmy	ρv^2_{max} Pa
	68.1	57	22	40	39.996	28.522	8.284	5.437	21.1	0.1776	634 196	15.22	5	50.51

Analysis:

The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and compressor station at km 123,00-123,46. Bulgaria to Greece operation with maximum flow.

Temperature in AGRS Dimitrowgrad are lower than 6°C for Greek gas –winter conditions and Bulgarian gas winter conditions , and minimum temperature is 1,904°C for Greek gas –winter conditions before Compressor station and 2,187°C for Bulgarian gas winter conditions at the same point.

Suction pressure varies from 30,36bar to 31,48bar.

Required power for Compressor station varies from 19,1 MW for Bulgarian gas winter conditions to 21,4 MW for Greek gas summer conditions.

$\rho gr\ gas$=0,764 kg/m³; γ (sp.gravity) $gr\ gas$=0.592

Conclusions:

There is no risk of hydrate formation along the pipeline.

As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

ρ *bg gas*=0,736 kg/m^3 ; γ (sp.gravity) *bg gas*=0.57 Compressibility factor is calculated in each segment of the model;	

TYPE B : Facility pressure drop 0.5 bar for GMS

7. HYDRAULIC SIMULATION WITHOUT OFFTAKES - facility pressure drop 0.5 bar for GMS

Hydraulic simulation I: ***Greece to Bulgaria operation***

- Hydraulic simulation I.A. Greek Gas – winter conditions
- Hydraulic simulation I.B. Greek Gas – summer conditions
- Hydraulic simulation I.C. Bulgarian Gas – winter conditions
- Hydraulic simulation I.D. Bulgarian Gas – summer conditions
- Hydraulic simulation I.E. Greek Code Gas – winter conditions
- Hydraulic simulation I.F. Greek Code Gas – summer conditions

Hydraulic simulation II: ***Bulgaria to Greece operation***

- Hydraulic simulation II.A. Greek Gas – winter conditions
- Hydraulic simulation II.B. Greek Gas – summer conditions
- Hydraulic simulation II.C. Bulgarian Gas – winter conditions
- Hydraulic simulation II.D. Bulgarian Gas – summer conditions
- Hydraulic simulation II.E. Greek Code Gas – winter conditions
- Hydraulic simulation II.F. Greek Code Gas – summer conditions

Hydraulic simulation III: ***Greece to Bulgaria operation – Supply Pressure from Komotini with Capacity of 1.4 bcmy***

- Hydraulic simulation III.A. Greek Gas – winter conditions
- Hydraulic simulation III.B. Greek Gas – summer conditions
- Hydraulic simulation III.C. Bulgarian Gas – winter conditions
- Hydraulic simulation III.D. Bulgarian Gas – summer conditions
- Hydraulic simulation III.E. Greek Code Gas – winter conditions
- Hydraulic simulation III.F. Greek Code Gas – summer conditions

Hydraulic simulation IV: ***Greece to Bulgaria operation – Supply Pressure from Komotini with Capacity of 3.08 bcmy***

- Hydraulic simulation IV.A. Greek Gas – winter conditions
- Hydraulic simulation IV.B. Greek Gas – summer conditions
- Hydraulic simulation IV.C. Bulgarian Gas – winter conditions
- Hydraulic simulation IV.D. Bulgarian Gas – summer conditions
- Hydraulic simulation IV.E. Greek Code Gas – winter conditions
- Hydraulic simulation IV.F. Greek Code Gas – summer conditions

Hydraulic simulation V: ***Greece to Bulgaria operation – with Compressor Station and Capacity of 5 bcmy***

- Hydraulic simulation V.A. Greek Gas – winter conditions
- Hydraulic simulation V.B. Greek Gas – summer conditions
- Hydraulic simulation V.C. Bulgarian Gas – winter conditions
- Hydraulic simulation V.D. Bulgarian Gas – summer conditions
- Hydraulic simulation V.E. Greek Code Gas – winter conditions
- Hydraulic simulation V.F. Greek Code Gas – summer conditions

Hydraulic simulation VI: ***Bulgaria to Greece operation – max flow with Compressor Station***

- Hydraulic simulation VI.A. Greek Gas – winter conditions
- Hydraulic simulation VI.B. Greek Gas – summer conditions
- Hydraulic simulation VI.C. Bulgarian Gas – winter conditions
- Hydraulic simulation VI.D. Bulgarian Gas – summer conditions

All above mentioned hydraulic simulation from I to IV are free flow conditions. Simulation V and VI are with compressor station on IGB pipeline which position is selected on the previous stage of the project.
The results are shown in tables below:

Capacity of the IGB in free flow conditions – *Greece to Bulgaria operation without offtakes*

I.A. Greek Gas – winter conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	44	42	40.27	6	0	6.789	0.601	3.570	0.688	9.74	87 312	2 095 488	0.688
2	45	42	41.03	6	0	6.537	0.206	6.380	1.230	31.10	155 354	3 728 496	1.225
3	46	42	41.80	6	0	6.195	0.108	8.345	1.610	53.20	203 147	4 875 528	1.602
4	47	42	42	6	0	5.988	0.043	9.990	1.927	76.25	243 344	5 840 256	1.919
5	48	42	42	6	0	5.988	-0.017	11.405	2.201	99.38	278 501	6 684 024	2.196
6	49	42	42	6	0	5.988	-0.077	12.720	2.454	123.61	310 582	7 453 968	2.449
7	50	42	42	6	0	5.987	-0.137	13.923	2.686	148.10	340 442	8 170 608	2.684
8	51	42	42	6	0	5.987	-0.198	15.063	2.905	173.35	368 888	8 853 312	2.908
9	52	42	42	6	0	5.987	-0.266	16.131	3.110	198.8	395 709	9 497 016	3.120
10	53	42	42	6	0	5.986	-0.335	17.151	3.306	224.74	421 452	10 114 848	3.323
11	54	42	42	6	0	5.986	-0.400	18.128	3.494	251.07	446 351	10 712 424	3.519
12	55	42	42	6	0	5.986	-0.468	19.072	3.675	277.90	470 455	11 290 920	3.709
13	56	42	42	6	0	5.986	-0.536	19.985	3.851	305.14	493 920	11 854 080	3.894
14	57	42	42	6	0	5.985	-0.601	20.903	4.027	333.82	517 063	12 409 512	4.077

I.B. Greek Gas – summer conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	44	42	40.57	22	40	30.400	21.487	4.168	0.803	13.27	90 479	2 171 496	0.713
2	45	42	41.33	22	40	27.778	20.958	6.939	1.337	36.79	152 109	3 650 616	1.199
3	46	42	41.99	22	40	26.679	20.407	8.961	1.727	61.35	197 261	4 734 264	1.555
4	47	42	42	22	40	25.948	19.988	10.637	2.050	86.44	234 823	5 635 752	1.851
5	48	42	42	22	40	25.359	19.650	12.119	2.336	112.21	268 169	6 436 056	2.114
6	49	42	42	22	40	24.841	19.367	13.467	2.596	138.60	298 659	7 167 816	2.355
7	50	42	42	22	40	24.505	19.121	14.731	2.839	165.80	327 347	7 856 328	2.581
8	51	42	42	22	40	24.301	18.904	15.906	3.065	193.29	354 146	8 499 504	2.792
9	52	42	42	22	40	24.132	18.708	17.007	3.277	220.98	379 471	9 107 304	2.992
10	53	42	42	22	40	23.989	18.529	18.083	3.484	249.82	404 237	9 701 688	3.187
11	54	42	42	22	40	23.863	18.363	19.106	3.680	278.89	427 896	10 269 504	3.374
12	55	42	42	22	40	23.751	18.207	20.093	3.870	308.45	450 836	10 820 064	3.554
13	56	42	42	22	40	23.655	18.063	21.059	4.055	338.82	473 382	11 361 168	3.732
14	57	42	42	22	40	23.567	17.925	21.988	4.233	369.37	495 169	11 884 056	3.904

I.C. Bulgarian Gas – winter conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	44	42	40.41	6	0	6.763	0.721	3.740	0.721	10.29	90 621	2 174 904	0.714
2	45	42	41.18	6	0	6.517	0.352	6.579	1.269	31.86	158 791	3 810 984	1.252
3	46	42	41.95	6	0	6.186	0.263	8.599	1.659	54.42	207 460	4 979 040	1.636
4	47	42	42	6	0	5.989	0.203	10.259	1.979	77.46	247 653	5 943 672	1.952
5	48	42	42	6	0	5.988	0.147	11.721	2.261	101.11	283 221	6 797 304	2.233
6	49	42	42	6	0	5.988	0.093	13.049	2.517	125.32	315 688	7 576 512	2.489
7	50	42	42	6	0	5.988	0.040	14.291	2.757	150.32	346 208	8 308 992	2.730
8	51	42	42	6	0	5.987	-0.017	15.445	2.979	175.57	374 703	8 992 872	2.954
9	52	42	42	6	0	5.987	-0.081	16.539	3.189	201.32	401 849	9 644 376	3.168
10	53	42	42	6	0	5.987	-0.144	17.570	3.387	227.21	427 689	10 264 536	3.372
11	54	42	42	6	0	5.987	-0.205	18.583	3.582	254.16	453 096	10 874 304	3.572
12	55	42	42	6	0	5.986	-0.269	19.549	3.767	281.27	477 481	11 459 544	3.764
13	56	42	42	6	0	5.986	-0.333	20.486	3.947	308.88	501 217	12 029 208	3.952
14	57	42	42	6	0	5.986	-0.393	21.404	4.123	337.18	524 623	12 590 952	4.136

I.D. Bulgarian Gas – summer conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	44	42	40.69	22	40	30.386	21.514	4.322	0.833	13.75	93 219	2 237 256	0.735
2	45	42	41.46	22	40	27.805	21.090	7.133	1.375	37.45	155 347	3 728 328	1.225
3	46	42	41.99	22	40	26.714	20.552	9.194	1.772	62.21	201 014	4 824 336	1.585
4	47	42	42	22	40	25.992	20.142	10.904	2.102	87.51	239 058	5 737 392	1.885
5	48	42	42	22	40	25.412	19.811	12.417	2.393	113.48	272 849	6 548 376	2.151
6	49	42	42	22	40	24.900	19.533	13.808	2.661	140.33	304 057	7 297 368	2.397
7	50	42	42	22	40	24.543	19.292	15.086	2.907	167.50	332 835	7 988 040	2.624
8	51	42	42	22	40	24.339	19.081	16.273	3.136	194.90	359 772	8 634 528	2.836
9	52	42	42	22	40	24.170	18.889	17.424	3.357	223.45	385 929	9 262 296	3.043
10	53	42	42	22	40	24.024	18.713	18.513	3.566	252.25	410 775	9 858 600	3.239
11	54	42	42	22	40	23.897	18.551	19.559	3.768	281.56	434 753	10 434 072	3.428
12	55	42	42	22	40	23.785	18.399	20.569	3.962	311.39	458 000	10 992 000	3.611
13	56	42	42	22	40	23.688	18.258	21.558	4.151	342.05	480 845	11 540 280	3.791
14	57	42	42	22	40	23.599	18.124	22.508	4.334	372.87	502 918	12 070 032	3.965

I.E. Greek Code Gas – winter conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	45	42	40.19	6	0	6.659	-0.641	5.231	1.009	25.01	138 952	3 334 848	1.095
2	57	42	42	6	0	5.982	-1.842	18.309	3.527	306.39	486 957	11 686 968	3.839

I.F. Greek Code Gas – summer conditions without offtakes

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, m^3/d	Flow St. Zagora, bcmy
1	45	42	40.63	22	40	27.631	20.219	6.013	1.159	33.05	137 602	3 302 448	1.085
2	57	42	42	22	40	23.384	16.781	19.548	3.763	349.26	463 084	11 114 016	3.651

Analysis:

The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad.

ρ *gr gas*=0,764 kg/m^3; γ (sp.gravity) *gr gas*=0,592

ρ *bg gas*=0,736 kg/m^3; γ (sp.gravity) *bg gas*=0.57

ρ *gr code gas*=0,914 kg/m^3; γ (sp.gravity) *gr code gas*=0,707

Compressibility factor is calculated in each segment of the model;

Conclusions:

In the all above cases pressure in the area of negative temperatures is about 49-50.5 bar – this means that the water dew point will be around: -5 °C to - 6 °C which is too far from the minimum temperatures in pipe. There is no risk of hydrate formation along the pipeline.

As can be seen from the - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

Capacity of the IGB in free flow conditions – *Bulgaria to Greece operation without offtakes*

II.A. Greek Gas – winter conditions

№	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.73	6	0	6.875	1.623	9.697	1.870	71.84	224 842	5 396 208	1.772

II.B. Greek Gas – summer conditions

№	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.92	22	40	26.014	18.846	10.040	1.935	77.01	214 748	5 153 952	1.693

II.C. Bulgarian Gas – winter conditions

№	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.84	6	0	6.872	1.766	9.900	1.910	72.14	227 657	5 463 768	1.795

II.D. Bulgarian Gas – summer conditions

№	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	35.02	22	40	26.068	18.957	10.242	1.974	77.21	217 602	5 222 448	1.716

II.E. Greek Code Gas – winter conditions

№	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.09	6	0	7.134	1.099	8.752	1.688	70.01	214 000	5 136 000	1.687

II.F. Greek Code Gas – summer conditions

№	P_{in} St. Zagora, bar	P_{out} Komotini, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow Komotini, m^3/h	Flow Komotini, m^3/d	Flow Komotini, bcmy
1	40.4	36.23	34.24	22	40	25.706	18.188	4.518	3.054	18.66	208 000	4 992 000	1.640

Analysis:	**Conclusions:**
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from Bulgaria to Greece. Flow rates at Komotini varies depending on the type of gas and the conditions(winter,summer) for specified initial and final pressure. ρ *gr gas*=0,764 kg/m^3; γ (sp.gravity) *gr gas*=0,592 ρ *bg gas*=0,736 kg/m^3; γ (sp.gravity) *bg gas*=0,57 ρ *gr code gas*=0,914 kg/m^3; γ (sp.gravity) *gr code gas*=0,707 Compressibility factor is calculated in each segment of the model;	There is no risk of hydrate formation along the pipeline. As can be seen from the - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

Capacity of the IGB – *Greece to Bulgaria operation without offtakes – Supply Pressure from Komotini with Capacity of 1.4 bcmy*

III.A. Greek Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	45.44	42	41.38	6	0	6.404	0.235	7.315	1.411	40.88	177 575	4.26	1.4

III.B. Greek Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	45.54	42	41.74	22	40	26.568	20.642	8.021	1.546	49.15	177 575	4.26	1.4

III.C. Bulgarian Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	45.37	42	41.46	6	0	6.399	0.312	7.379	1.423	40.07	177 575	4.26	1.4

III.D. Bulgarian Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	45.47	42	41.82	22	40	26.692	20.822	8.078	1.557	48.03	177 575	4.26	1.4

III.E. Greek Code Gas – winter conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	45.79	42	40.78	6	0	6.319	-0.761	6.686	1.290	36.5	177 575	4.26	1.4

III.F. Greek Code Gas – summer conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	45.93	42	41.32	22	40	26.555	19.624	7.724	1.489	54.30	177 575	4.26	1.4

Analysis:

The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from Greece to Bulgaria and capacity of 1,4 bcmy.

ρ *gr gas*=0,764 kg/m³; γ (sp.gravity) *gr gas*=0,592

ρ *bg gas*=0,736 kg/m³; γ (sp.gravity) *bg gas*=0,57

ρ *gr code gas*=0,914 kg/m³; γ (sp.gravity) *gr code gas*=0,707

Compressibility factor is calculated in each segment of the model;

Conclusions:

In the above case pressure in the area of negative temperatures is about 40-41 bar – this means that the water dew point will be around: -7.5 °C to - 8 °C which is too far from the minimum temperatures in pipe.
There is no risk of hydrate formation along the pipeline.
As can be seen from the - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

Capacity of the IGB – *Greece to Bulgaria operation without offtakes – Supply Pressure from Komotini with Capacity of 3.08 bcmy*

IV.A. Greek Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	51.80	42	42	6	0	5.987	-0.202	16.122	3.109	198.58	390 665	9.38	3.08

IV.B. Greek Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	52.44	42	42	22	40	24.065	18.627	17.530	3.377	234.78	390 665	9.38	3.08

IV.C. Bulgarian Gas – winter conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	51.59	42	42	6	0	5.987	-0.056	16.264	3.136	194.69	390 665	9.38	3.08

IV.D. Bulgarian Gas – summer conditions

Nº	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	52.18	42	42	22	40	24.138	18.853	17.658	3.402	229.49	390 665	9.38	3.08

IV.E. Greek Code Gas – winter conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	52.82	42	42	6	0	5.984	-1.438	14.696	2.833	197.4	390 665	9.38	3.08

IV.F. Greek Code Gas – summer conditions

№	P_{in} Komotini, bar	P_{out} St. Zagora, bar	P_{min}, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
1	53.62	42	42	22	40	23.712	16.633	6.345	3.204	252.9	390 665	9.38	3.08

Analysis:	**Conclusions:**
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and free flow from Greece to Bulgaria and capacity of 3,08 bcmy. ρ *gr gas*=0,764 kg/m³; γ (sp.gravity) *gr gas*=0,592 ρ *bg gas*=0,736 kg/m³; γ (sp.gravity) *bg gas*=0,57 ρ *gr code gas*=0,914 kg/m³; γ (sp.gravity) *gr code gas*=0,707 Compressibility factor is calculated in each segment of the model;	In all the above cases in winter conditions pressure in the area of negative temperatures is about 46-46.3 bar – this means that the water dew point will be around: -6.5 °C to -7 °C which is too far from the minimum temperatures in pipe. There is no risk of hydrate formation along the pipeline. As can be seen from the - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

Capacity of the IGB – *Greece to Bulgaria operation without offtakes – with Compressor Station and Capacity of 5 bcmy*

V.A. Greek Gas – winter conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	41.97	6	0	5.999	-0.604	10.24	5.604	80.11	3 000		637 196	15.29	5.0237
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
	58.74	52	6	0	39.998	30.530	20.70	3.988	327.4	8.12	0.072	634 196	15.22	5

V.B. Greek Gas – summer conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	40.58	22	40	21.993	16.634	11.23	6.15	96.35	3 300		637 496	15.30	5.026
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
	58.78	52	22	40	39.999	34.497	22.56	4.343	388.8	9.53	0.0792	634 196	15.22	5

V.C. Bulgarian Gas – winter conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	42.44	6	0	5.984	-0.758	10.37	5.674	79.15	3 000		637 196	15.29	5.0237
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
	59.45	52	6	0	39.998	30.351	20.91	4.030	321.9	8.13	0.072	634 196	15.22	5

V.D. Bulgarian Gas – summer conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	41.12	22	40	21.997	17.039	11.34	6.211	94.65	3 300		637 496	15.30	5.026
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
	58.62	52	22	40	39.999	34.525	22.76	4.382	381.3	9.17	0.0792	634 196	15.22	5

V.E. Greek Code Gas – winter conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	39.86	6	0	5.979	-2.825	9.41	5.147	80.93	3 300		637 496	15.30	5.026
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
	59.45	52	6	0	39.998	30.785	18.41	3.544	309.78	9.42	0.0792	634 196	15.22	5

V.F. Greek Code Gas – summer conditions

Before CS	P_{in} Komotini, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from Komotini, mcmd	Flow from Komotini, bcmy
	57	37.90	22	40	22.852	14.305	10.53	5.767	101.35	3 500		637 696	15.305	5.028
After CS	P discharge, bar	P_{out} St. Zagora, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow St. Zagora, m^3/h	Flow St. Zagora, mcmd	Flow St. Zagora, bcmy
	59.50	52	22	40	39.999	34.266	21.269	4.093	413.47	11.36	0.084	634 196	15.22	5

Analysis:	Conclusions:
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and compressor station at km 123,00-123,46. Greece to Bulgaria operation with capacity of	There is no risk of hydrate formation along the pipeline. As can be seen from the - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

5 bcmy. Suction pressure varies from 37,9bar to 42,44bar. Required power for Compressor station varies from 8,12 MW for Greek gas winter conditions to 11,36 MW for Greek code gas summer conditions. ρ *gr gas*=0,764 kg/m^3; γ (sp.gravity) *gr gas*=0,592 ρ *bg gas*=0,736 kg/m^3; γ (sp.gravity) *bg gas*=0,57 ρ *gr code gas*=0,914 kg/m^3; γ (sp.gravity) *gr code gas*=0,707 Compressibility factor is calculated in each segment of the model;	

Before CS	P_{in} St. Zagora, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy
	40.4	30.58	6	0	5.991	1.233	18.59	3.555	264	7 000		641 196	15.39	5.055
After CS	P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Komotini, mcmd	Flow Komotini, bcmy
	68.60	57	6	0	39.992	23.527	11.01	5.342	92.61	20	0.168	634 196	15.22	5

VI.B. Greek Gas – summer conditions

Before CS	P_{in} St. Zagora, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy
	40.4	29.63	22	40	21.988	19.134	20.10	3.842	308.7	7 500		641 696	15.4	5.059
After CS	P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Komotini, mcmd	Flow Komotini, bcmy
	68.8	57	22	40	39.996	28.391	11.34	5.326	98.25	22.37	0.18	634 196	15.22	5

VI.C. Bulgarian Gas – winter conditions

Before CS	P_{in} St. Zagora, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy
	40.4	30.88	6	0	5.991	1.542	18.74	3.584	258.5	7 000		641 196	15.39	5.055
After CS	P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Komotini, mcmd	Flow Komotini, bcmy
	68.3	57	6	0	39.991	23.560	11.1	5.419	90.68	19.7	0.168	634 196	15.22	5

VI.D. Bulgarian Gas – summer conditions

Before CS	P_{in} St. Zagora, bar	P suction, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Flow CS, m^3/h		Flow till CS, m^3/h	Flow from St. Zagora, mcmd	Flow from St. Zagora, bcmy
	40.4	29.99	22	40	21.989	19.390	20.23	3.867	301.2	7 500		641 696	15.4	5.059
After CS	P discharge, bar	P_{out} Komotini, bar	T ambient °C	T Air °C	T_{max} °C	T_{min} °C	v_{max} m/s	v_{min} m/s	ρv^2_{max} Pa	Power Required, MW	Fuel Rate, mcmd	Flow Komotini, m^3/h	Flow Komotini, mcmd	Flow Komotini, bcmy
	68.5	57	22	40	39.996	28.542	11.45	5.403	96.49	22	0.18	634 196	15.22	5

Analysis:	Conclusions:
The above calculations applied hydraulic simulation without offtakes for AGRS Kardjali and AGRS Dimitrovgrad and compressor station at km 123,00-123,46. Bulgaria to Greece operation with maximum flow. Suction pressure varies from 29,63bar to 30,88bar. Required power for Compressor station varies from 19,7 MW for Bulgarian gas winter conditions to 22,37 MW for Greek gas summer conditions. ρ *gr gas*=0,764 kg/m^3 ; γ (sp.gravity) *gr gas*=0.592 ρ *bg gas*=0,736 kg/m^3 ; γ (sp.gravity) *bg gas*=0.57 Compressibility factor is calculated in each segment of the model;	There is no risk of hydrate formation along the pipeline. As can be seen from the graph - ρv^2 criteria - erosion is not a risk anywhere along the pipe.

General conclusions:

Both hydraulic simulations (with facility pressure drop 0.0 bar for AGI and with facility pressure drop 0.5 bar for GMS) show that the project bi-directional pipeline system IGB is with optimal characteristics and would be able to transport a gas flowrate of 4 bcmy regardless of gas composition without intermediate compression and initial pressure 57bar at Komotini and 42bar at Stara Zagora.
With compressor station at km 123,00-123,46 on IGB route the system can transport a gas flowrate of 5 bcmy regardless of gas composition.
As can be seen from the attached charts for the modification of the temperature along the route there is no subzero temperatures in the range of block valves and regular operation of valves on surface (avoid freezing) is guaranteed.
There is no risk of hydrate formation along the pipeline. Erosion is not a risk anywhere along the pipe.

8. ASSESSING OF HEATING REQUIREMENT DURING FIRST FILLING OF THE PIPELINE

In the tables above are given values for pressure and temperature drop in the all specific points of the pipeline. Based on our experience and in item 3 and item 4 of the Technical assignment, we think that the biggest load is during first filling of the pipeline and therefore we have implemented the following calculations.

In accordance with the methodology Руководство по разчету основных параметров заполнения газопроводов газом для изпытания Р 401-80", ВНИИСТ - Guidance for calculation of basic parameters of filling the pipeline with gas testing, VNIIST) for first filling of the pipeline formula (40) is : t = 43 h (time to full filling the pipeline DN 800 with length L = 182.54 km).

At the starting point of the fill in empty gas pipeline it is necessary to limit the flow of gas supplied quantity that's filled, due to the high speeds of the gas. For this reason, in the limit of q_v (20) = 55 000 m3/h, ensure velocity ≤ 15 m/s. On this basis, the amount of heat required to heat the gas to fill the pipeline initially in the most unfavorable period is:

INNITIAL DATA:

V=55 000 m3/h – maximum gas flow rate

Pmax=57 bar - maximum gas pressure(Greece to Bulgaria operation)

Pr=1 bar - gas pressure in the empty gas pipeline

tp1= 5° C - inlet gas temperature

tr= 5° C - gas temperature afret reduction

CALCULATION:

Calculation of the temperature difference obtained from the reduction of the gas

Δtp=k (Pmax - Pr) + tr - tp1

k = 0,4 °/bar – empirical value from Jules-Thomson effect

Δtp= 0,4 (57-1) +5 -5 = 22,4 ° C

Heater gas outlet temperature

tp2= Δtp + tp1

tp2= 22,4 + 5 = 27,4° C

Heat required

Q= V. ρn . cp . Δtp /3600, kW

ρn= 0.719 kg/m3 – normal conditions

cp= 2.56 kJ/kgK - specific heat capacity of the gas as a function of Pmax и tsrp / of a chart/

Q= 55000. 0,719. 2,56. 22,4/ 3600 = 630 кW

According to the project: Heaters provided for the GMS "Komotini" - respectively GMS "Stara Zagora" are two pieces with power P = 4.46 MW each and they ensure heating requirement during first filling of the pipeline.

Sample fill modes:

№	Gas flow rate [m3/h]	Power to heat [kW]	Conditions
1	qv (20) ≤ 30 000	Q= 30000.0,719.2,56.22,8/3600=350	(empty gas pipeline)
2	qv (20) ≤ 55 000	Q= 55000.0,719.2,56.22,4/3600=630	(up to 1bar pressure is reached in the entry point of the pipeline)
3	qv (20) ≤ 80 000	Q= 80000.0,719.2,56.22,0/3600=900	(up to 2bar pressure is reached in the entry point of the pipeline)
4	qv (20) ≤ 108 000	Q= 108000.0,719.2,56.21,6/3600=1193	(up to 3bar pressure is reached in the entry point of the pipeline)
5	qv (20) ≤ 135 000	Q= 13500.0,719.2,56.21,2/3600=1463	(up to 4bar pressure is reached in the entry point of the pipeline)
6	qv (20) ≤ 163 000	Q= 163000.0,719.2,56.20,8/3600=1733	(up to 5bar pressure is reached in the entry point of the pipeline)
7	qv (20) ≤ 190 000	Q= 190000.0,719.2,56.20,4/3600=1982	(up to 6bar pressure is reached in the entry point of the pipeline)
8	qv (20) ≤ 215 000	Q= 215000.0,719.2,56.20,0/3600=2200	(up to 7bar pressure is reached in the entry point of the pipeline)
9	qv (20) ≤ 245 000	Q= 245000.0,719.2,56.19,6/3600=2455	(up to 8bar pressure is reached in the entry point of the pipeline)
10	qv (20) ≤ 270 000	Q= 270000.0,719.2,56.19,2/3600=2650	(up to 9bar pressure is reached in the entry point of the pipeline)
11	qv (20) ≤ 300 000	Q= 300000.0,719.2,56.18,8/3600=2884	(up to 10bar pressure is reached in the entry point of the pipeline)

After reaching a pressure of P = 10bar in entry point, the restriction of the gas flow rate is off and until the final fill is used full capacity of the station. Of the thermal calculation shows that the heaters ensure heating requirement during first filling of the pipeline.

9. ASSESSING OF HEATING REQUIREMENT FOR HYDRAULIC SIMULATION LEADING TO A TEMPERATURE BELOW 6°C AT GAS METERING STATIONS

In the above calculations appear temperature changes along the route and values in all specific points of the pipeline . In some of the hydraulic simulations (for winter conditions) can be seen that the inlet temperature is below 6°C (assumed as a minimum inlet temperature for heaters at the stations).

For this reason it was made following verification with the aim of assessing whether that selected heating requirement cover these temperature differences of approximately 3°C.

INNITIAL DATA:

qv(20)= 390 665m^3/h – maximum gas flow rate (3.08 BCMY)

Pmax=43 bar - gas pressure in the gas pipeline

Pr=38bar – minimum gas pressure in the gas pipeline after GMS

tp1= 3° C - inlet gas temperature

CALCULATION:

Calculation of the temperature difference obtained from the reduction of the gas

Δtp=k (Pmax - Pr) + tr - tp1° C

k = (0,35-0,5) 0,5 °/bar – empirical value from Jules-Thomson effect

Heater gas outlet temperature

tp2= Δtp + tp1

Heat required

Q= V. ρn . cp . Δtp /3600, kW

ρn= 0.719 kg/m3 – normal conditions

cp= 2.56 kJ/kgK - specific heat capacity of the gas as a function of Pmax и tsrp / of a chart/

Q= 390 665 x 0.719 x 2.56 x 4.5/3600= 0.899MW

Standart efficiency of Heat exchanger is about 92%

0.899/0.92=0.98 MW- minimal needed thermal power

According to the project: Heaters provided for the GMS "Komotini" - respectively GMS "Stara Zagora" are two pieces with power P = 4.46 MW each and they will run in regular operation.